ECOSYSTEMS

Ecosystems provide humans with food, clean water, and a variety of other services that can be affected by climate change. This chapter looks at some of the ways that climate change affects ecosystems, including changes in wildfires, streams and lakes, bird migration patterns, and plant growth.

WHY DOES IT MATTER?

Changes in the Earth's climate can affect ecosystems by altering the water cycle, habitats, animal behavior—such as nesting and migration patterns—and the timing of natural processes such as flower blooms. Changes that disrupt the functioning of ecosystems may increase the risk of harm or even extinction for some species. While wildfires occur naturally, more frequent and more intense fires can significantly disrupt ecosystems, damage property, put people and communities at risk, and create air pollution problems even far away from the source.

While plants and animals have adapted to environmental change for millions of years, the climate changes being experienced now could require adaptation on larger and faster scales than current species have successfully achieved in the past, thus increasing the risk of extinction or severe disruption for many species.

Summary of Key Points

Wildfires. Since 1983, the United States has had an average of 72,000 recorded wildfires per year. Of the 10 years with the largest acreage burned, nine have occurred since 2000, with many of the largest increases occurring in western states. The proportion of burned land suffering severe damage each year has ranged from 5 to 22 percent.

Streamflow. Changes in temperature, precipitation, snowpack, and glaciers can affect the rate of streamflow and the timing of peak flow. Over the last 73 years, minimum, maximum, and average flows have changed in many parts of the country—some higher, some lower. Nearly half of the rivers and streams measured show peak winter-spring runoff happening at least five days earlier than it did in the mid-20th century.

Great Lakes Water Levels and Temperatures. Water levels in most of the Great Lakes have declined in the last few decades. Water levels in lakes are influenced by water temperature, which affects evaporation rates and ice formation. Since 1995, average surface water temperatures have increased by a few degrees for Lakes Superior, Michigan, Huron, and Ontario. Less of a temperature change has been observed in Lake Erie.

Bird Wintering Ranges. Some birds shift their range or alter their migration habits to adapt to changes in temperature or other environmental conditions. Long-term studies have found that bird species in North America have shifted their wintering grounds northward by an average of more than 40 miles since 1966, with several species shifting by hundreds of miles. On average, bird species have also moved their wintering grounds farther from the coast, consistent with inland winter temperatures becoming less severe.

Leaf and Bloom Dates. Leaf growth and flower blooms are examples of natural events whose timing can be influenced by climate change. Observations of lilacs and honeysuckles in the contiguous 48 states suggest that first leaf dates and bloom dates show a great deal of year-to-year variability. Leaf and bloom events are generally happening earlier throughout the North and West but later in much of the South.

Community Connection: Cherry Blossom Bloom Dates in Washington, D.C. "Peak" bloom dates of the iconic cherry trees in Washington, D.C., recorded since the 1920s, indicate that cherry trees are blooming slightly earlier than in the past. Bloom dates are key to planning the Cherry Blossom Festival, one of the region's most popular spring attractions.

Wildfires

This indicator tracks the frequency, extent, and severity of wildfires in the United States.

KEY POINTS

- Since 1983, the National Interagency Fire Center has documented an average of 72,000 wildfires per year (see Figure 1). Compiled data from the Forest Service suggest that the actual total may be even higher for the first few years of nationwide data collection that can be compared. The data do not show an obvious trend during this time.
- The extent of area burned by wildfires each year appears to have increased since the 1980s. According to National Interagency Fire Center data, of the 10 years with the largest acreage burned, nine have occurred since 2000 (see Figure 2). This period coincides with many of the warmest years on record nationwide (see the U.S. and Global Temperature indicator on p. 28).
- The late 1990s were a period of transition in certain climate cycles that tend to shift every few decades.[1] This shift—combined with other ongoing changes in temperature, drought, and snowmelt—may have contributed to warmer, drier conditions that have fueled wildfires in parts of the western United States.[2,3]
- Of the total area burned each year from 1984 to 2012, the proportion of burned land suffering severe damage has ranged from 5 to 22 percent (see Figure 3).
- Land area burned by wildfires varies by state. Fires burn more land in the western United States than in the East, and parts of the West and Southwest show the largest increase in burned acreage between the first half of the record (1984–1998) and the second half (1999–2012) (see Figure 4).

Together, forests, shrubland, and grassland cover more than half of the land area in the United States.[4] These ecosystems are important resources, both environmentally and economically. Although wildfires occur naturally and play a long-term role in the health of these ecosystems, climate change threatens to increase the frequency, extent, and severity of fires through increased temperatures and drought (see the U.S. and Global Temperature and Drought indicators on pp. 28 and 38). Earlier spring melting and reduced snowpack (see the Snowpack indicator on p. 70) result in decreased water availability during hot summer conditions, which in turn contributes to an increased wildfire risk, allowing fires to start more easily and burn hotter. In addition to climate change, other factors—like the spread of insects, land use, and management practices, including fire suppression—play an important role in wildfire frequency and intensity. All of these factors influencing wildfires vary greatly by region, as do variations in precipitation, wind, temperature, vegetation types, and landscape conditions. Therefore, understanding changes in fire characteristics requires a regional perspective and consideration of many factors.[5]

Wildfires have the potential to harm property, livelihoods, and human health. The recreation and timber industries depend on healthy forests, and wildfire smoke has been directly linked to poor air quality and illness, even in communities far downwind.[6] Fire-related threats are increasing, especially as more people live in and around forests, grasslands, and other natural areas.[7] The United States spends more than $1 billion every year to fight wildfires,[8] and these efforts have resulted in the deaths of hundreds of firefighters since 1910.[9]

Beyond the human impact, wildfires also affect the Earth's climate. Forests in particular store large amounts of carbon. When they burn, they release carbon dioxide into the atmosphere, which in turn contributes to additional climate change.

ABOUT THE INDICATOR

This indicator defines wildfires as "unplanned, unwanted wildland fire[s]" in forests, shrubland, and grassland, where "the objective is to put the fire out."[10] This indicator tracks three aspects of wildfires over time: the total number of fires (frequency), the total land area burned (extent), and the degree of damage that fires cause to the landscape (severity). The total area and total number of fires are tracked by the National Interagency Fire Center, which compiles reports from local, state, and federal agencies that are involved in fighting wildfires. The U.S. Forest Service tracked similar data using a different reporting system until 1997. Those data have been added to this indicator for comparison. Wildfire severity is measured by comparing the "greenness" of satellite images taken before and after a fire to classify how severely the land has been burned. Burn severity provides an indication of the ecological damage and how long the effects of wildfires are likely to last.

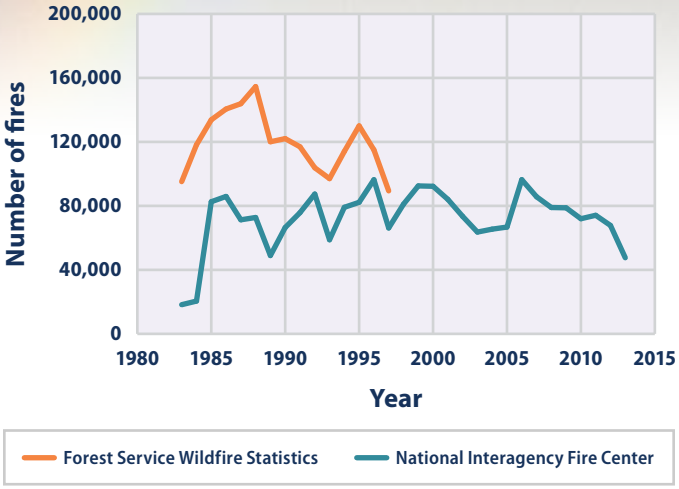
Although some nationwide fire data have been collected since the early 1900s, this indicator starts in 1983 (Figures 1 and 2) and 1984 (Figures 3 and 4), when nationwide data collection became more complete and standardized.

INDICATOR NOTES

Many environmental impacts associated with climate change can affect wildfire frequency, extent, or severity, including changes in temperature, precipitation, and drought. Human activities and land management practices also affect wildfire activity, and preferred practices in wildfire management have evolved over time, from older policies that favored complete wildfire prevention to more recent policies of wildfire suppression and controlled burns. While this indicator is limited to "wildland" fires, it includes fires that encroach on—or perhaps started in—developed areas. Increased development in previous wild lands could influence trends in wildfire frequency and extent. The total number of fires may also vary due to reporting irregularities, as fires that split or merge together across jurisdictional lines may be counted differently.

Along with the influence of ongoing climate change, wildfire patterns can be influenced by natural climate cycles that tend to shift every few decades. Thus, the approximately 30 years of data shown here may not be enough to draw conclusions about long-term trends. While a longer record would be ideal, data from before 1983 are not consistent enough nationally to be included in this indicator.

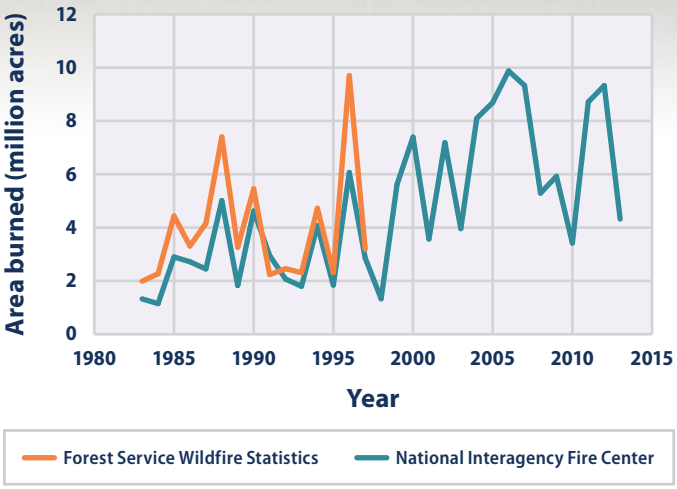
Figure 1. Wildfire Frequency in the United States, 1983–2013



This figure shows the total number of wildfires per year from 1983 to 2013. These totals include all reported wildfires, which can be as small as just a few acres. The two lines represent two different reporting systems; though Forest Service statistics (orange line) stopped being compiled in 1997 and will not be updated, they are shown here for comparison.

Data source: NIFC, 2014;[11] USDA Forest Service, 2014[12]

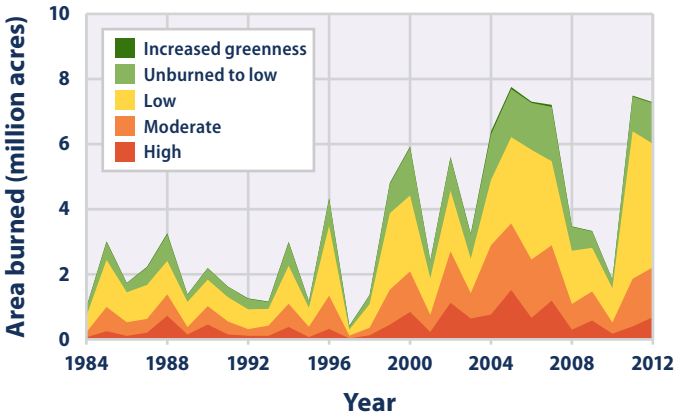
Figure 2. Wildfire Extent in the United States, 1983–2013



This figure shows annual wildfire-burned area (in millions of acres) from 1983 to 2013. The two lines represent two different reporting systems; though Forest Service statistics (orange line) stopped being compiled in 1997 and will not be updated, they are shown here for comparison.

Data source: NIFC, 2014;[13] USDA Forest Service, 2014[14]

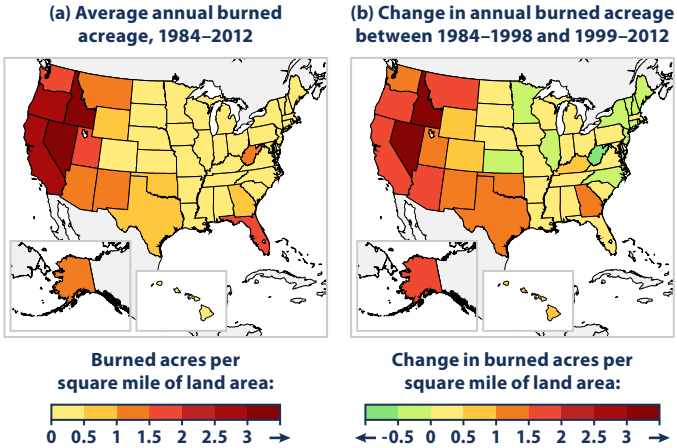
Figure 3. Damage Caused by Wildfires in the United States, 1984–2012



This figure shows the distribution of acreage burned by large wildfires, based on the level of damage caused to the landscape—a measure of wildfire severity. Large wildfires are defined as fires with an area larger than 1,000 acres in the western United States and 500 acres in the eastern United States. The total acreage shown in Figure 3 is slightly less than the total in Figure 2 because Figure 3 is limited to large fires and because a few areas did not have sufficient satellite imagery to allow damage to be assessed.

Data source: MTBS, 2014[15]

Figure 4. Land Area Burned by Wildfires by State, 1984–2012

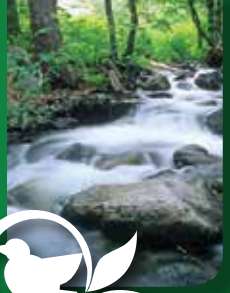


These maps show the number of acres burned in each state as a proportion of that state's total land area. For reference, there are 640 acres in a square mile; therefore, an average burned area of 6.4 acres per square mile would mean that fires burned 1 percent of a state's total land area. (a) The map on the left shows the average extent of fires per year from 1984 to 2012. Darker-shaded states have the largest proportion of acreage burned. (b) The map on the right shows how burned acreage has changed over time, based on a simple comparison between the first half of the available years (1984–1998) and the second half (1999–2012).

Data source: MTBS, 2014[16]

DATA SOURCES

The full set of wildfire frequency and burned acreage data in Figures 1 and 2 comes from the National Interagency Fire Center, which compiles wildfire reports sent from local, state, and federal entities that are involved in fighting fires. These data are available online at: www.nifc.gov/fireInfo/fireInfo_statistics.html. Additional data were provided by the U.S. Forest Service based on a different set of records, referred to as Smokey Bear Reports. Burn severity data and state-by-state acreage totals in Figures 3 and 4 come from a multi-agency project called Monitoring Trends in Burn Severity, which maintains a database of wildfire events across the United States. These data are publicly available at: http://mtbs.gov/data/search.html.



Streamflow

This indicator describes trends in the amount of water carried by streams across the United States, as well as the timing of runoff associated with snowmelt.

KEY POINTS

- Over the past 73 years, seven-day low flows have generally increased in the Northeast and Midwest (in other words, on the days of lowest flows, streams in these areas are carrying more water than before). In parts of the Southeast and the Pacific Northwest, low flows have generally decreased (that is, streams are carrying less water than before). Overall, sites show more increases than decreases (see Figure 1).
- Three-day high-flow trends vary from region to region across the country. For example, streams in the Northeast have generally seen an increase or little change in high flows since 1940, while some West Coast streams have seen a decrease and others have seen an increase. Overall, sites show more increases than decreases (see Figure 2).
- The largest changes in annual average streamflow have taken place in the Northeast and Midwest. Other regions saw few substantial changes. Overall, sites show more increases than decreases (see Figure 3).
- Nearly half of the streams studied show winter-spring runoff happening more than five days earlier than in the mid-20th century. The largest changes occurred in the Pacific Northwest and Northeast (see Figure 4).

Streamflow is a measure of the rate at which water is carried by rivers and streams, and it represents a critical resource for people and the environment. Changes in streamflow can directly influence the supply of drinking water and the amount of water available for irrigating crops, generating electricity, and other needs. In addition, many plants and animals depend on streamflow for habitat and survival.

Streamflow naturally varies over the course of a year. For example, rivers and streams in many parts of the country have their highest flows when snow melts in the spring and their lowest flows in late summer. The amount of streamflow is important because very high flows can cause erosion, flooding, and ecosystem disruption, while very low flows can diminish water quality, harm fish, and reduce the amount of water available for people. The timing of high flow is important because it affects the ability of reservoir managers to store water to meet needs later in the year. In addition, some plants and animals (such as fish that migrate) depend on a particular pattern of streamflow as part of their life cycles.

Climate change can affect streamflow in several ways. Changes in the amount of snowpack and earlier spring melting (see the Snowpack indicator on p. 70) can alter the size and timing of high streamflows. Because of the relationship between precipitation and runoff, more precipitation will potentially cause higher average streamflow in some places, while heavier storms (see the Heavy Precipitation indicator on p. 36) could lead to larger peak flows. However, more frequent or severe droughts could reduce streamflow in certain areas.

ABOUT THE INDICATOR

The U.S. Geological Survey measures streamflow in rivers and streams across the United States using continuous monitoring devices called stream gauges. This indicator is based on 193 stream gauges located in areas where trends will not be substantially influenced by dams, reservoir management, wastewater treatment facilities, or land-use change. The indicator also excludes stream gauges with substantially overlapping watershed areas.

This indicator examines four important measures of streamflow conditions that occur during the course of a year. Figure 1 shows trends in low flow conditions, which are commonly calculated by averaging the lowest seven consecutive days of streamflow in a year. In many locations, this method captures the year's driest conditions. Figure 2 shows trends in high flow conditions, which are commonly calculated by averaging the highest three consecutive days of streamflow in a year. Three days is an optimal length of time to characterize runoff associated with large storms and peak snowmelt. Figure 3 shows changes in the annual average streamflow, which is calculated by averaging daily flows over the entire year.

Figure 4 shows trends in the timing of winter and spring runoff. This measure is limited to 56 stream gauges in areas where at least 30 percent of annual precipitation falls as snow. Scientists look at the total volume of water that passes by a gauge between January 1 and June 30, then determine the date when exactly half of that water has gone by. This date is called the winter-spring center of volume date. A long-term trend toward an earlier date could be caused by earlier spring snowmelt, more precipitation falling as rain instead of snow, or other changes in precipitation patterns.

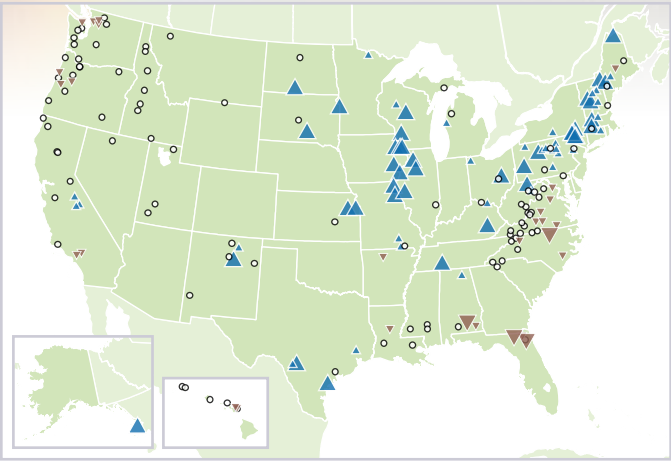
INDICATOR NOTES

Streamflow measurements were used from gauges in areas where streamflow is not highly affected by human influences such as dams, land development, or changes in land cover. However, changes in land cover and land use over time could still influence streamflow trends at some streams. The gauges used for this indicator are not evenly distributed across the country.

DATA SOURCES

Streamflow data were collected by the U.S. Geological Survey. These data came from a set of gauges in watersheds with minimal human impacts, which have been classified as reference gauges.[17] Daily average streamflow data are stored in the National Water Information System and are publicly available at: http://waterdata.usgs.gov/nwis.

Figure 1. Seven-Day Low Streamflows in the United States, 1940–2012

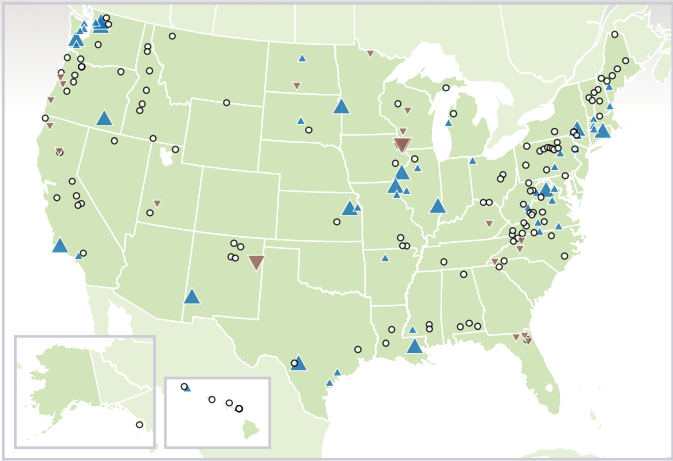


More than 50% decrease | 20% to 50% decrease | 20% decrease to 20% increase | 20% to 50% increase | More than 50% increase

This map shows percentage changes in the minimum annual rate of water carried by rivers and streams across the country, based on the long-term rate of change from 1940 to 2012. Minimum streamflow is based on the consecutive seven-day period with the lowest average flow during a given year.

Data source: USGS, 2014[18]

Figure 2. Three-Day High Streamflows in the United States, 1940–2012

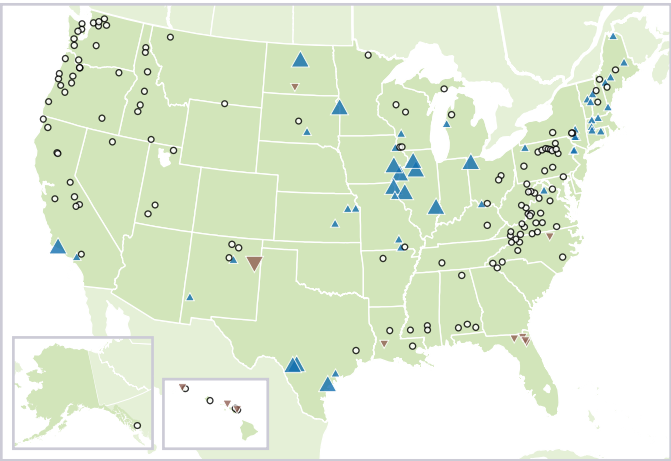


More than 50% decrease | 20% to 50% decrease | 20% decrease to 20% increase | 20% to 50% increase | More than 50% increase

This map shows percentage changes in the maximum annual rate of water carried by rivers and streams across the country, based on the long-term rate of change from 1940 to 2012. Maximum streamflow is based on the consecutive three-day period with the highest average flow during a given year.

Data source: USGS, 2014[19]

Figure 3. Annual Average Streamflow in the United States, 1940–2012

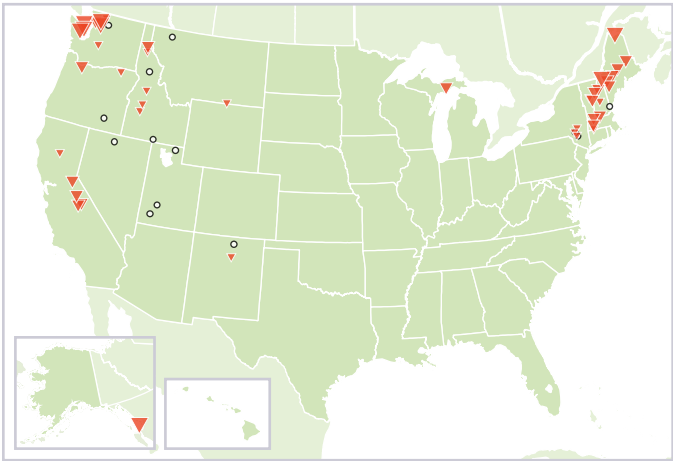


More than 50% decrease | 20% to 50% decrease | 20% decrease to 20% increase | 20% to 50% increase | More than 50% increase

This map shows percentage changes in the annual average rate of water carried by rivers and streams across the country, based on the long-term rate of change from 1940 to 2012. This map is based on daily streamflow measurements, averaged over the entire year.

Data source: USGS, 2014[20]

Figure 4. Timing of Winter-Spring Runoff in the United States, 1940–2012



More than 10 days earlier | 5 to 10 days earlier | 2 to 5 days earlier | 2 days earlier to 2 days later | 2 to 5 days later | 5 to 10 days later | More than 10 days later

This map shows changes in the timing of annual high spring flow carried by rivers and streams from 1940 to 2012. This analysis focuses on parts of the country where streamflow is strongly influenced by snowmelt. Trends are based on the winter-spring center of volume, which is the date when half of the streamflow between January 1 and June 30 of each year has passed a streamflow gauge.

Data source: USGS, 2014[21]

Great Lakes Water Levels and Temperatures

This indicator measures water levels and surface water temperatures in the Great Lakes.

KEY POINTS

- Water levels in the Great Lakes have fluctuated since 1860. Over the last few decades, they appear to have declined for most of the Great Lakes (see Figure 1). However, the most recent levels are all within the range of historical variation.
- Since 1995, average surface water temperatures have increased by a few degrees for Lakes Superior, Michigan, Huron, and Ontario (see Figure 2). Less change has been observed in water temperature in Lake Erie.
- Recent increases in water temperature have mostly been driven by warming during the spring and summer months (see Figure 2). These trends could relate in part to an earlier thawing of winter ice (see the Lake Ice indicator on p. 62).

The Great Lakes, consisting of Lake Superior, Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario, form the largest group of freshwater lakes on Earth. These lakes support a variety of ecosystems and play a vital role in the economy of the eight neighboring states and the Canadian province of Ontario, providing drinking water, shipping lanes, fisheries, recreational opportunities, and more.

Water level and water temperature are two important and interrelated indicators of weather and climate change in the Great Lakes. Water level (the height of the lake surface above sea level) is influenced by many factors, including precipitation, snowmelt runoff, drought, evaporation rates, and people withdrawing water for multiple uses. Water temperature is influenced by many factors, too, but most directly by air temperature.

In recent years, warmer surface water temperatures in the Great Lakes have contributed to lower water levels by increasing rates of evaporation and causing lake ice to form later than usual (see the Lake Ice indicator on p. 62), which extends the season for evaporation.[22] Lower water levels in the Great Lakes forced ships to reduce their cargo tonnage by 5 to 8 percent between 1997 and 2000, which increased shipping costs. Lower water levels can also affect water supplies, the usability of infrastructure such as docks and piers, and shoreline ecosystems. These types of disruptions from low water levels are expected to continue as the climate changes.[23]

Another possible effect of warmer water, reduced ice cover, and increased evaporation is a corresponding increase in precipitation over nearby land, especially "lake effect" snow (see the Snowfall indicator on p. 66).[24] Rising water temperatures are also expected to expand the ranges of and give new advantages to some invasive species such as the zebra mussel, and to encourage the growth of certain waterborne bacteria that can make people ill.[25,26]

ABOUT THE INDICATOR

This indicator analyzes water levels and surface water temperatures in the Great Lakes. Water levels are recorded by gauges along the shore of each lake, some of which have been operated since the 1800s. Pre-1918 data came from one water level gauge per lake. Data since 1918 have come from a designated set of gauges in each lake. Figure 1 shows annual water level anomalies, or differences, in feet compared with the average water levels in each lake from 1860 to 2013. Lakes Michigan and Huron are combined because they are connected at the same water level.

Surface water temperatures are measured by satellites. Figure 2 shows annual average temperatures over the entire surface of each lake, along with the pattern of daily temperatures over the course of the year. This figure's data begin in 1995, which was the first year with complete satellite data for all five lakes.

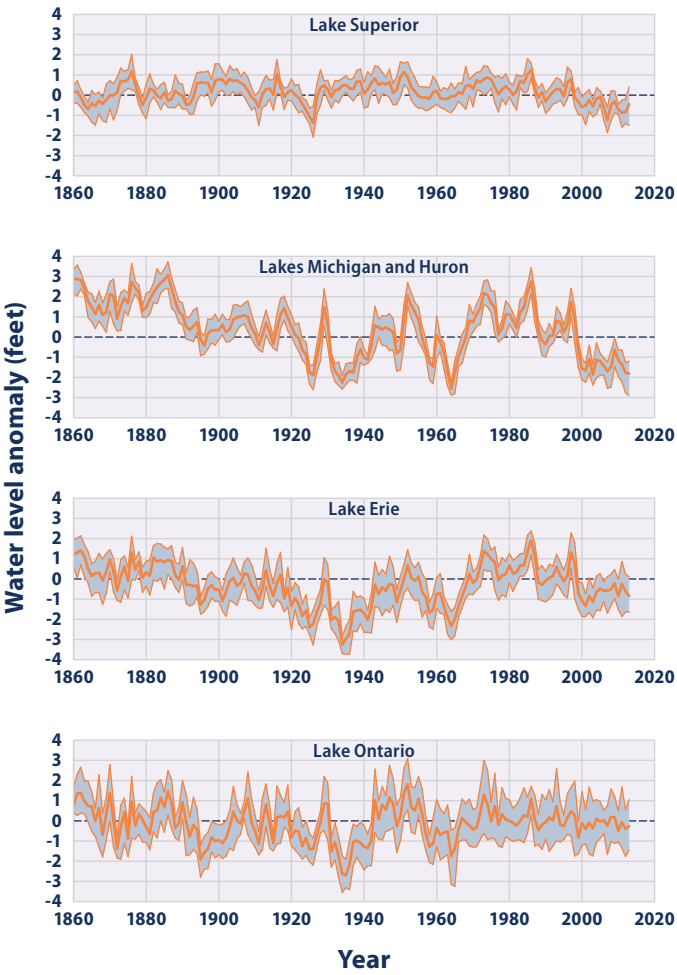
INDICATOR NOTES

While climate change influences water levels, human activities such as dredging can also play a role. For example, the St. Clair river opening was enlarged in the 1910s, 1930s, and 1960s, contributing to greater outflows from Lakes Michigan and Huron.[27] Similarly, natural year-to-year variability and other factors such as human use and wastewater discharges can influence water temperatures.

DATA SOURCES

Water level data were provided by the Canadian Hydrographic Service and the National Oceanic and Atmospheric Administration's Center for Operational Oceanographic Products and Services, and can be downloaded from: www.glerl.noaa.gov/data/now/wlevels/levels.html. Surface water temperature data were provided by the National Oceanic and Atmospheric Administration's Great Lakes Environmental Research Laboratory (satellite data at: http://coastwatch.glerl.noaa.gov).

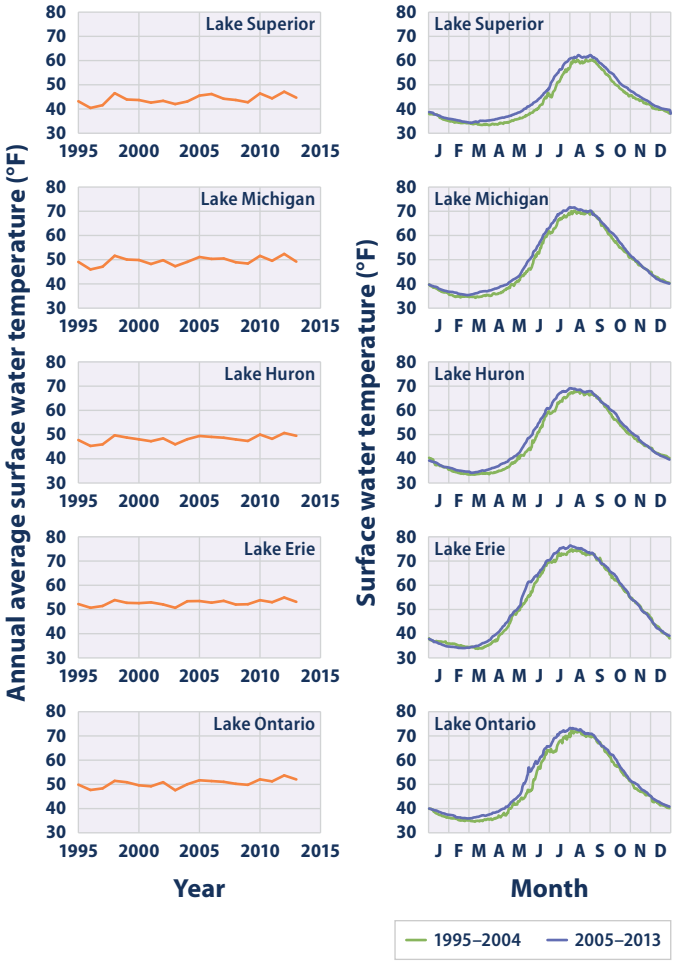
Figure 1. Water Levels of the Great Lakes, 1860–2013



This figure displays how water levels in each of the Great Lakes have changed since 1860. For each year, the shaded band shows the range of monthly average water levels, and the line in the middle shows the annual average. The graph uses the 1981 to 2010 average as a baseline for depicting the change. Choosing a different baseline period would not change the shape of the data over time. Lakes Michigan and Huron are shown together because they are connected at the same water level.

Data source: NOAA, 2014[28]

Figure 2. Surface Water Temperatures of the Great Lakes, 1995–2013



This figure shows the average surface water temperatures in each of the Great Lakes, as measured by satellites. The graphs on the left show annual averages, while the graphs on the right show how average daily temperatures have changed between two time periods. The full time period has been divided approximately in half for comparison: 2005–2013 (nine years) versus 1995–2004 (10 years).

Data source: NOAA, 2014[29]

Bird Wintering Ranges

This indicator examines changes in the winter ranges of North American birds.

KEY POINTS

- Among 305 widespread North American bird species, the average mid-December to early January center of abundance moved northward by more than 40 miles between 1966 and 2013 (see Figure 1). Trends in center of abundance moving northward can be closely related to increasing winter temperatures.[30]
- On average, bird species have also moved their wintering grounds farther from the coast since the 1960s (see Figure 2). A shift away from the coasts can also relate to changes in winter temperatures. Inland areas tend to experience more extreme cold than coastal areas, but those extremes are becoming less severe as the climate warms overall.[31]
- Some species have moved farther than others. A total of 48 species have moved northward by more than 200 miles. Of the 305 species studied, 186 (61 percent) have shifted their wintering grounds northward since the 1960s, while 82 (27 percent) have shifted southward. Some others have not moved at all.

Changes in climate can affect ecosystems by influencing animal behavior and ranges. Birds are a particularly good indicator of environmental change for several reasons:

- Each species of bird has adapted to or evolved to favor certain habitat types, food sources, and temperature ranges. In addition, the timing of certain events in their life cycles—such as migration and reproduction—is driven by cues from the environment. For example, many North American birds follow a regular seasonal migration pattern, moving north to feed and breed in the summer, then moving south to spend the winter in warmer areas. Changing conditions can influence the distribution of both migratory and non-migratory birds as well as the timing of important life cycle events.
- Birds are easy to identify and count, and thus there is a wealth of scientific knowledge about their distribution and abundance. People have kept detailed records of bird observations for more than a century.
- There are many different species of birds living in a variety of habitats, including water birds, coastal birds, and land birds. If a change in behavior or range occurs across a range of bird types, it suggests that a common external factor might be the cause.

Temperature and precipitation patterns are changing across the United States (see the U.S. and Global Temperature indicator on p. 28 and the U.S. and Global Precipitation indicator on p. 34). Some bird species can adapt to generally warmer temperatures by changing where they live—for example, by migrating farther north in the summer but not as far south in the winter, or by shifting inland as winter temperature extremes grow less severe. Non-migratory species might shift as well, expanding into newly suitable habitats while moving out of areas that become less suitable. Other types of birds might not adapt to changing conditions and could experience a population decline as a result. Climate change can also alter the timing of events that are based on temperature cues, such as migration and breeding (especially egg-laying).

ABOUT THE INDICATOR

This indicator looks collectively at the "center of abundance" of hundreds of widespread North American bird species over a 48-year period. The center of abundance is a point on the map that represents the middle of each species' distribution. If a whole population of birds were to shift generally northward, one would see the center of abundance shift northward as well.

For year-to-year consistency, this indicator uses observations from the National Audubon Society's Christmas Bird Count, which takes place every year in early winter. The Christmas Bird Count is a long-running citizen science program in which individuals are organized by the National Audubon Society, Bird Studies Canada, local Audubon chapters, and other bird clubs to identify and count bird species. The data presented in this indicator were collected from more than 2,000 locations throughout the United States and parts of Canada. At each location, skilled observers follow a standard counting procedure to estimate the number of birds within a 15-mile diameter "count circle" over a 24-hour period. Study methods remain generally consistent from year to year. Data produced by the Christmas Bird Count go through several levels of review before Audubon scientists analyze the final data, which have been used to support a wide variety of peer-reviewed studies.

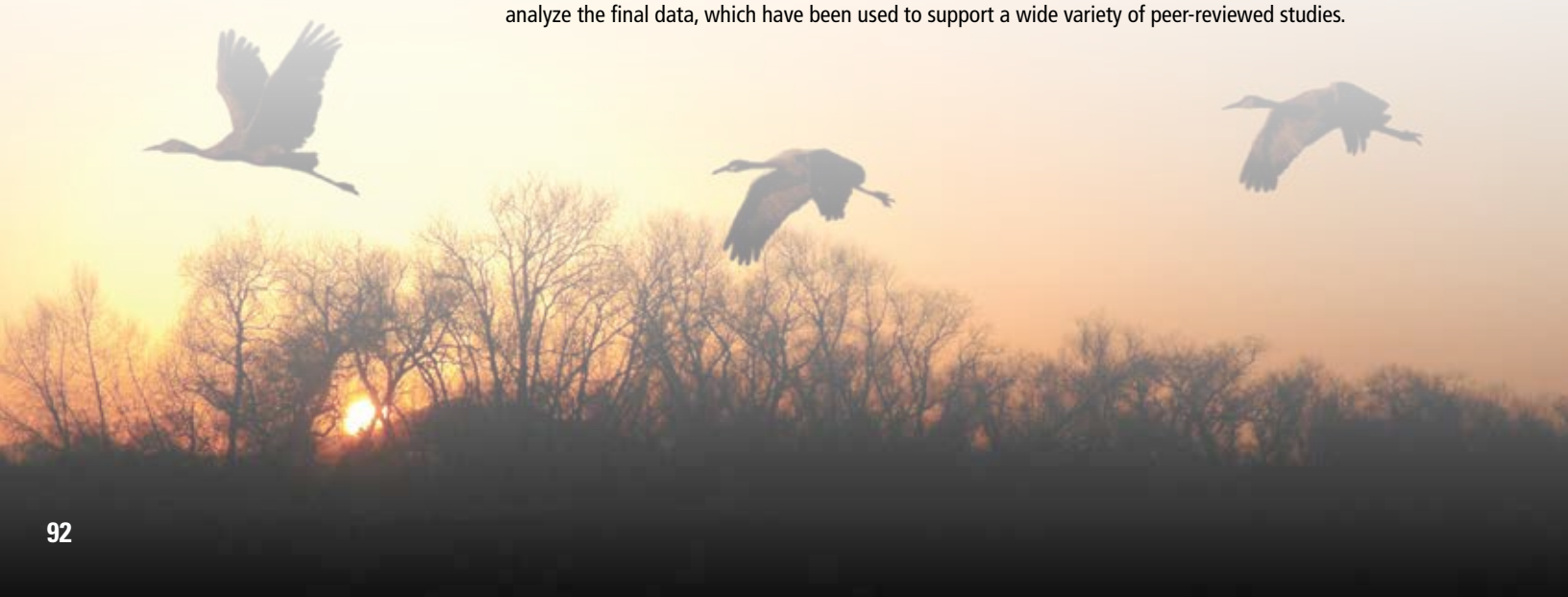
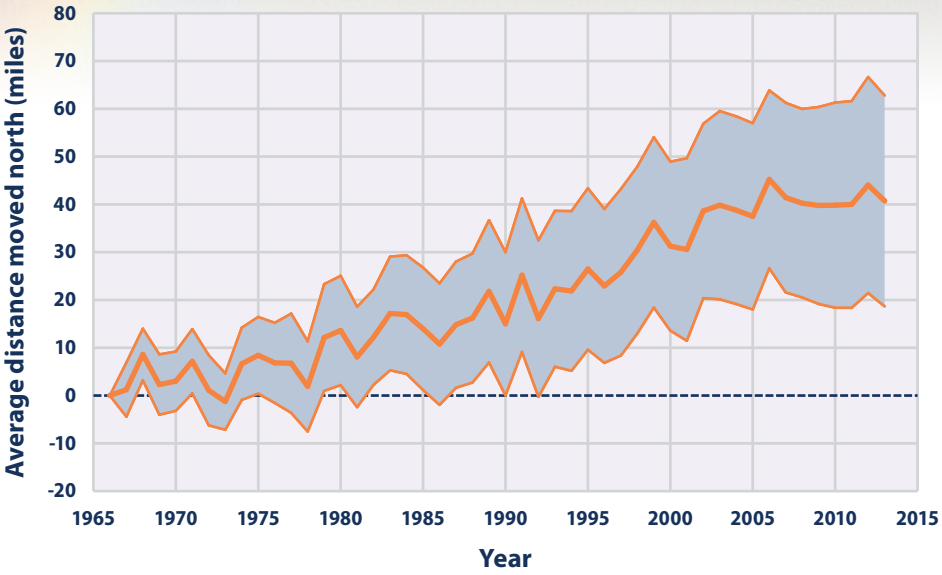


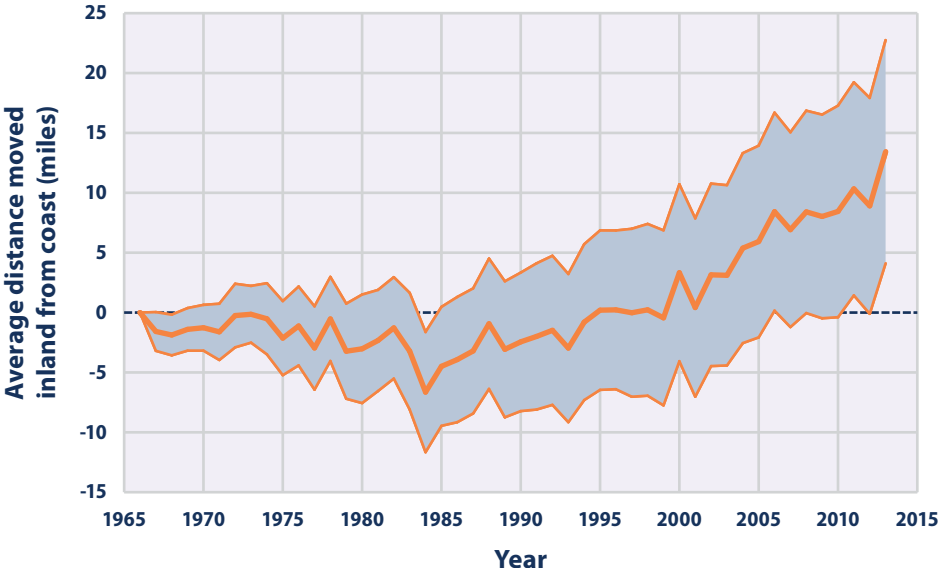
Figure 1. Change in Latitude of Bird Center of Abundance, 1966–2013



This figure shows annual change in latitude of bird center of abundance for 305 widespread bird species in North America from 1966 to 2013. Each winter is represented by the year in which it began (for example, winter 2013–2014 is shown as 2013). The shaded band shows the likely range of values, based on the number of measurements collected and the precision of the methods used.

Data source: National Audubon Society, 2014[32]

Figure 2. Change in Distance to Coast of Bird Center of Abundance, 1966–2013



This figure shows annual change in distance to the coast of bird center of abundance for 272 widespread bird species in North America from 1966 to 2013. This figure covers 272 species instead of the 305 species shown in Figure 1 because 33 of the species in Figure 1 need access to salt water, which means they cannot move inland. Each winter is represented by the year in which it began (for example, winter 2013–2014 is shown as 2013). The shaded band shows the likely range of values, based on the number of measurements collected and the precision of the methods used.

Data source: National Audubon Society, 2014[33]

INDICATOR NOTES

Many factors can influence bird ranges, including food availability, habitat alteration, and interactions with other species. As a result, some of the birds included in this indicator might have moved north for reasons other than changing temperatures. This indicator does not show how responses to climate change vary among different types of birds. For example, a more detailed National Audubon Society analysis found large differences among coastal birds, grassland birds, and birds adapted to feeders, which all have different abilities to adapt to temperature changes.[34]

Some data variations can be caused by differences among count circles, such as inconsistent level of effort by volunteer observers, but these differences are carefully corrected in Audubon's statistical analysis.

DATA SOURCES

Bird center of abundance data were collected by the annual Christmas Bird Count organized by the National Audubon Society and Bird Studies Canada. Recent and historical Christmas Bird Count data are available at: http://birds.audubon.org/christmas-bird-count. The National Audubon Society published a previous version of this analysis in 2009;[35] it is available at: www.audubon.org/bird/bacc/index.html.

Leaf and Bloom Dates

This indicator examines the timing of leaf growth and flower blooms for two widely distributed plants in the United States.

KEY POINTS

- First leaf and bloom dates in lilacs and honeysuckles in the contiguous 48 states show a great deal of year-to-year variability, which makes it difficult to determine whether a statistically meaningful change has taken place. However, earlier dates appear more prevalent in the last few decades (see Figure 1).
- Leaf and bloom events are generally happening earlier throughout the North and West but later in much of the South (see Figures 2 and 3). This observation is generally consistent with regional differences in temperature change (see the U.S. and Global Temperature indicator on p. 28).
- Other studies have looked at trends in leaf and bloom dates across all of North America and the entire Northern Hemisphere. These studies have also found a trend toward earlier spring events—some more pronounced than the trends seen in just the contiguous 48 states.[36]

The timing of natural events, such as flower blooms and animal migration, can be influenced by changes in climate. Phenology is the study of such important seasonal events. Phenological events are influenced by a combination of environmental factors, including temperature, light, rainfall, and humidity. Different plant and animal species respond to different cues.

Scientists have high confidence that the earlier arrival of spring events is linked to recent warming trends in global climate.[37] Disruptions in the timing of these events can have a variety of impacts on ecosystems and human society. For example, an earlier spring might lead to longer growing seasons (see the Length of Growing Season indicator on p. 80), more abundant invasive species and pests, and earlier and longer allergy seasons. Unusually warm weather in late winter can create a "false spring" that triggers the new growth of plants to begin too early, leaving them vulnerable to any subsequent frosts.

Because of their close connection with climate, the timing of phenological events can be used as an indicator of the sensitivity of ecological processes to climate change. Two particularly useful indicators of the timing of spring events are the first leaf dates and the first bloom dates of lilacs and honeysuckles, which have an easily monitored flowering season, a relatively high survival rate, and a large geographic distribution. The first leaf date in these plants relates to the timing of events that occur in early spring, while the first bloom date is consistent with the timing of later spring events, such as the start of growth in forest vegetation.[38]

ABOUT THE INDICATOR

This indicator shows trends in the timing of first leaf dates and first bloom dates in lilacs and honeysuckles across the contiguous 48 states. Because many of the phenological observation records in the United States are less than 40 years long, and because these records may have gaps in time or space, computer models have been used to provide a more complete understanding of long-term trends nationwide.

The models for this indicator were developed using data from the USA National Phenology Network, which collects ground observations from a network of federal agencies, field stations, educational institutions, and citizens who have been trained to log observations of leaf and bloom dates. For consistency, observations were limited to a few specific types of lilacs and honeysuckles. Next, models were created to relate actual leaf and bloom observations with records from nearby weather stations. Once scientists were able to determine the relationship between climate factors (particularly temperatures) and leaf and bloom dates, they used this knowledge to estimate leaf and bloom dates for earlier years based on historical weather records. They also used the models to estimate how leaf and bloom dates would have changed in a few areas (mostly in the far South) where lilacs and honeysuckles are not widespread.

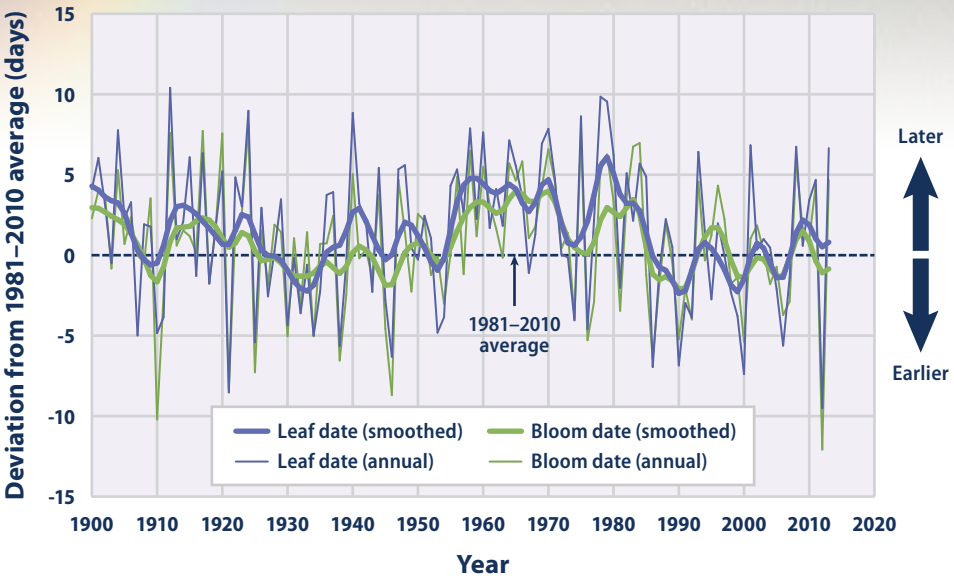
This indicator uses data from several hundred weather stations throughout the contiguous 48 states. The exact number of stations varies from year to year. For each year, the timing of first leaf and first bloom at each station was compared with the 1981 to 2010 average to determine the number of days' "deviation from normal." This indicator presents the average deviation across all stations, along with maps that compare the most recent 10-year period (2004–2013) with a mid-20th-century baseline (1951–1960) at individual stations. These time periods were chosen to match published studies.[39]

INDICATOR NOTES

Plant phenological events are studied using several data collection methods, including satellite images, models, and direct observations. Locational differences, the use of varying data collection methods, and different phenological indicators (such as leaf or bloom dates for different types of plants) can lead to a range of estimates of the arrival of spring.

Climate is not the only factor that can affect phenology. Observed variations can also reflect plant genetics, changes in the surrounding ecosystem, and other factors. This indicator minimizes the influence of genetic variations by relying on cloned plants (that is, plants with no genetic differences).

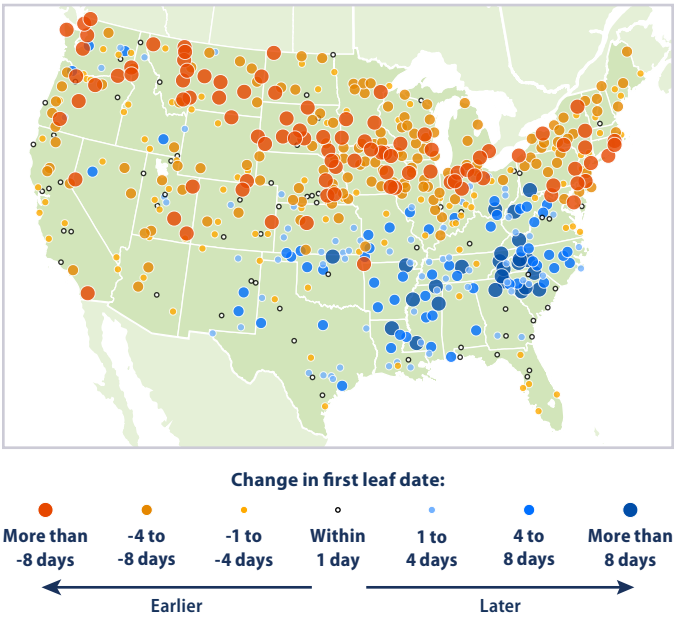
Figure 1. First Leaf and Bloom Dates in the Contiguous 48 States, 1900–2013



This figure shows modeled trends in lilac and honeysuckle first leaf dates and first bloom dates across the contiguous 48 states, using the 1981 to 2010 average as a baseline. Positive values indicate that leaf growth and blooming began later in the year, and negative values indicate that leafing and blooming occurred earlier. The thicker lines were smoothed using a nine-year weighted average. Choosing a different long-term average for comparison would not change the shape of the data over time.

Data source: Schwartz, 2013[40]

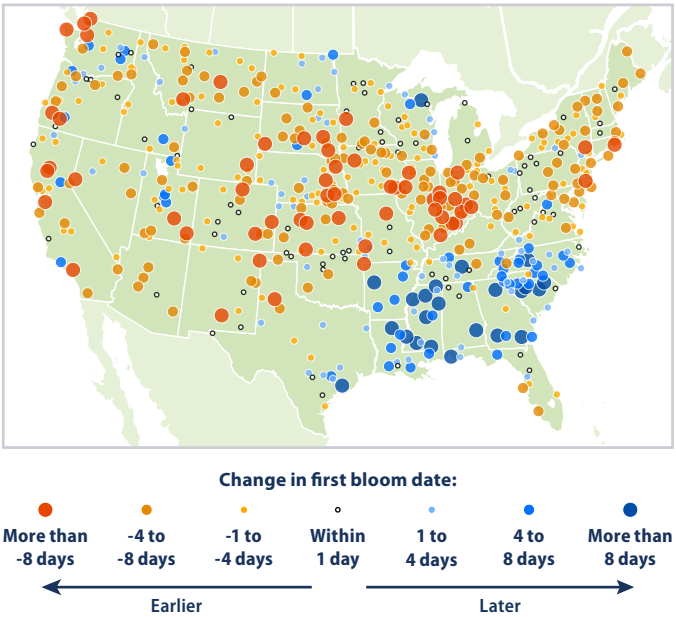
Figure 2. Change in First Leaf Date Between 1951–1960 and 2004–2013



This figure shows modeled trends in lilac and honeysuckle first leaf dates at weather stations across the contiguous 48 states. This map compares the average first leaf date during two 10-year periods.

Data source: Schwartz, 2013[41]

Figure 3. Change in First Bloom Date Between 1951–1960 and 2004–2013



This figure shows modeled trends in lilac and honeysuckle first bloom dates at weather stations across the contiguous 48 states. This map compares the average first bloom date during two 10-year periods.

Data source: Schwartz, 2013[42]

DATA SOURCES

Leaf and bloom observations were compiled by the USA National Phenology Network and are available at: www.usanpn.org. This indicator is also based on climate data that were provided by the U.S. Historical Climatology Network and are available at: www.ncdc.noaa.gov/oa/climate/research/ushcn. Data for this indicator were analyzed using methods described by Schwartz et al. (2013).[43]

Cherry Blossom Bloom Dates in Washington, D.C.

KEY POINTS

- Based on the entire 94 years of data in Figure 1, Washington's blossoms reach their peak on April 4 in an average year. By comparison, the peak bloom date in 2014 was April 10.
- Peak bloom date for the cherry trees is occurring earlier than it did in the past. Since 1921, peak bloom dates have shifted earlier by approximately five days.
- While the length of the National Cherry Blossom Festival has continued to expand, the Yoshino cherry trees have bloomed near the beginning of the festival in recent years. During some years, the festival missed the peak bloom date entirely.

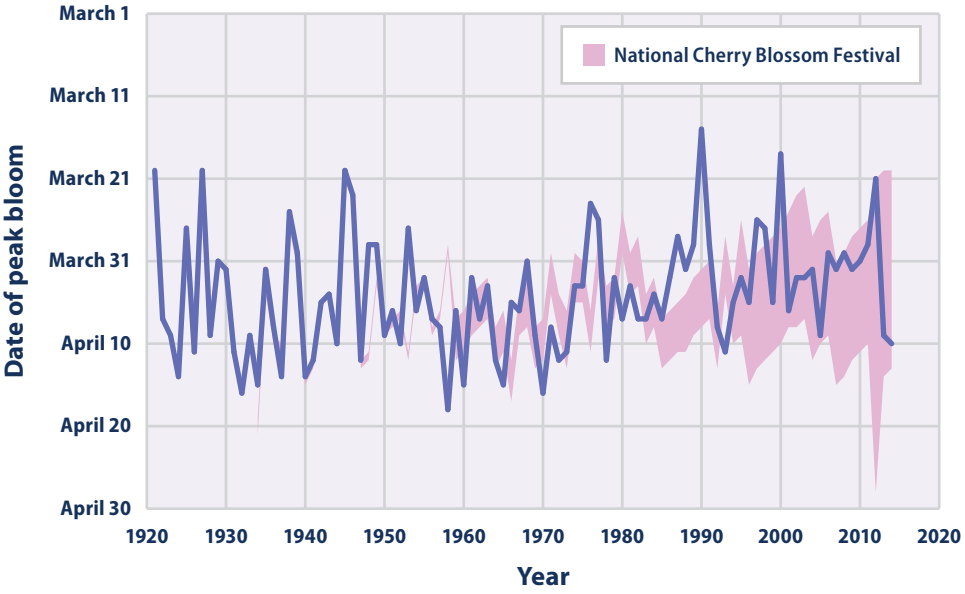
In Washington, D.C., the arrival of spring brings a splash of color as the city's iconic cherry trees burst into bloom. The city has enjoyed cherry blossoms each year dating back to 1912, when Japan gave 3,020 cherry trees to the United States as a gift of friendship. There are currently almost 3,800 of these trees around Washington's Tidal Basin, and the beautiful blooms set against the backdrop of the national monuments bring more than 1.5 million visitors to the area every year during the National Cherry Blossom Festival. Not surprisingly, the Festival is planned to coincide with the peak bloom of the cherry trees every year.

The exact timing of peak bloom varies from year to year, and it is largely driven by local temperatures during the winter and early spring. As the Leaf and Bloom Dates indicator (p. 94) explains, scientists have very high confidence that recent warming trends in global climate are causing spring events such as leaf growth and flower blooms to happen earlier.[44] In the case of Washington's cherry blossoms, earlier bloom dates could affect tourism and the local economy.

The peak bloom date for the most common type of cherry tree around Washington's Tidal Basin—the Yoshino variety—has been carefully estimated and recorded since 1921 by the National Park Service. The peak bloom date is defined as the day when 70 percent of the blossoms are in full bloom.

Figure 1 shows how the peak bloom date of the Yoshino cherry trees has changed since 1921. It also shows the dates of the National Cherry Blossom Festival, which has grown to several weeks as its popularity has expanded. As Figure 1 shows, there is considerable variability in the peak bloom date, which makes predicting the exact timing difficult. Each year, meteorologists, city planners, the National Park Service, and more than one million tourists speculate about the timing of peak bloom.

Figure 1. Peak Bloom Date for Cherry Trees Around Washington, D.C.'s Tidal Basin, 1921–2014



This figure shows the peak bloom date each year for the main type of cherry tree around the Tidal Basin in Washington, D.C. The peak bloom date occurs when 70 percent of the blossoms are in full bloom. The shaded band shows the timing of the annual National Cherry Blossom Festival. The festival began in 1934 but was not held during World War II.

Data source: National Park Service, 2014[45]

NOTES

In addition to winter and early spring temperatures, the timing of the peak bloom for cherry trees can be affected by other weather, climate, and location factors. For example, extended growing periods and warmer autumns could affect bloom dates by altering other stages of cherry tree growth.[46]

DATA SOURCES

Peak bloom dates and festival dates were provided by the National Park Service. The data shown here and other information about Washington's cherry trees can be found online at: www.nps.gov/cherry.